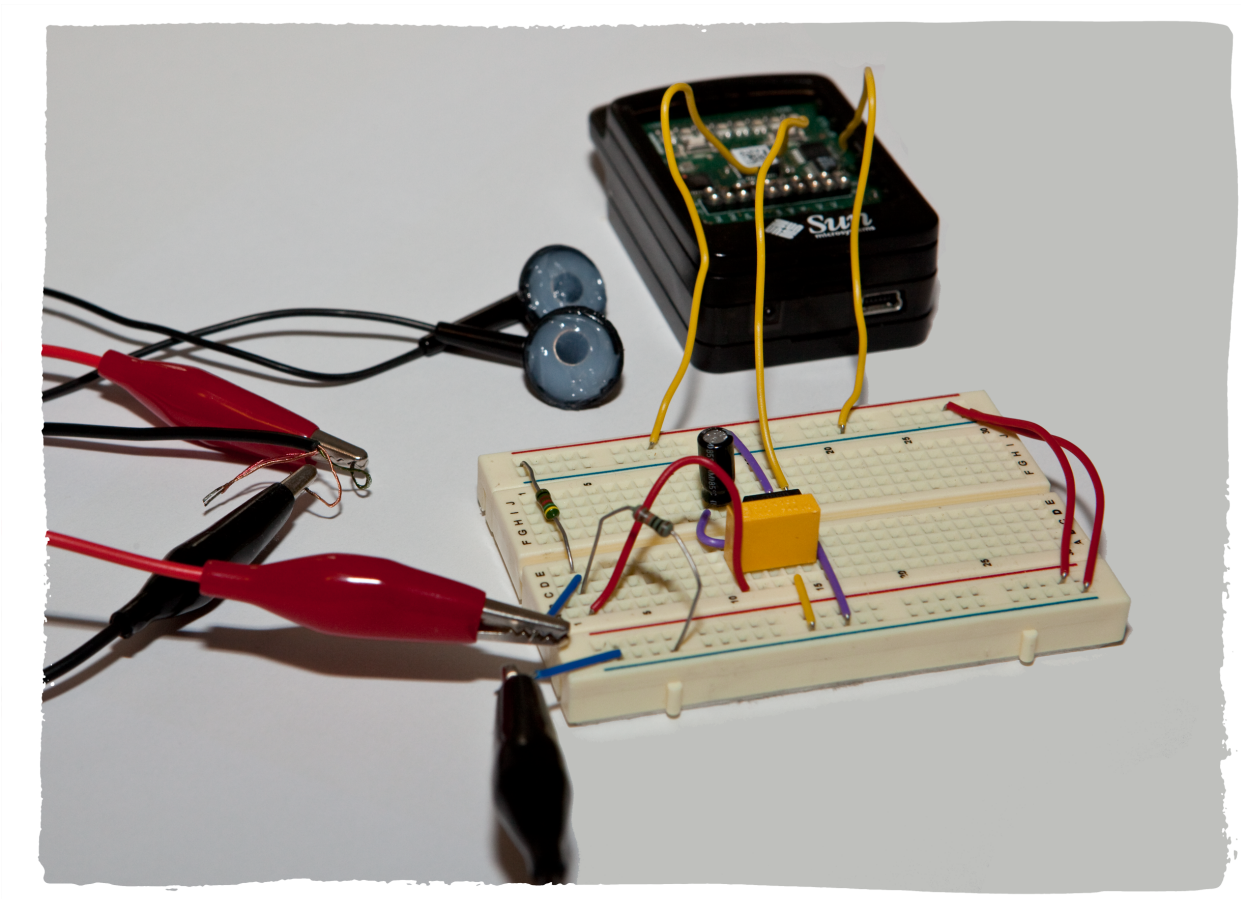
Hydrophone equipped mote

by Sidsel Jensen



Department of Computer Science
University of Copenhagen
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Abstract

Underwater sensor networks is a novel area within sensor networks. Recently there has been a growing interest in underwater wireless sensor networks due to its advantages and benefits in a wide spectrum of applications in aquatic environments. The main challenges of deploying such a network are the traditional ones of cost and limited battery resources of individual sensor nodes, but also consideration to the water environment and the difficult access possibilities once deployed. As a result both hardware and software must be carefully designed. In this project we present the design and implementation of a small-scale prototype for a hydrophone equipped sensor network for long-term deployment in the arctic area.

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Chapter 1

Introduction

The surface of our globe is covered by 70 percent water, yet doing underwater data acquisition is cumbersome. The traditional approach for remote ocean monitoring is to deploy underwater sensors that record data during the monitoring mission, and then at a later point recover the instruments, but this approach has a number of disadvantages[1].

- Real time monitoring is not possible.
- No interaction is possible between onshore control systems and the monitoring instruments.
- If failures or misconfigurations occur, its not possible to detect it before the retrieval of the instruments
- The amount of data is limited by the capacity of the onboard storage devices

Underwater sensor nodes and networks enable real time applications for oceanographic data collection, pollution monitoring and offshore exploration, but the water also introduces a number of challenges for sensor network systems, such as low communication bandwidth, large propagation delays, floating node mobility and high error probability. The lifetime of the application is limited by the battery capacity and the limited energy harvesting possibilities (solar energy and wave-generation). And the underwater sensors themselves are prone to fouling and corrosion.

1.1 Application constraints

To make matters worse the environmental conditions in the arctic area are harsh. Sensor networks primarily has four types of sensor activities (sensing, transmitting, receiving, and computing), which are all put to the test in extreme weather conditions. MANA[2]

[1] http://www.ece.gatech.edu/research/labs/bwn/UWASN/
[2] http://www.itu.dk/mana/

is a research project with the goal of improving scientific data acquisition in polar regions. The goal of this project is *to explore the possibility of adding a hydrophone equipped sensor network mote to the current MANA research installation* located in a freshwater lake in North-East Greenland.

Hydrophones are highly versatile sensors with many possible functions, as their sensing capabilities can vary from pure sound monitoring as an aid to the study of marine life and the environment, to seismic activity, localization as a sonar or as underwater communication devices.

The design of the hydrophone equipped sensor network will be bound by a number of hard requirements as well as the effect of the arctic deployment environment. The solution should be able to operate under the following conditions and constraints:

- It will be deployed in a freshwater lake in North-East Greenland (GPS coverage is low in the polar regions)
- The temperature range will be from +20 to -40 degrees Celcius
- The depth of the lake is about 6 meters with ice covering the lake during winter with about 2 meters thickness
- We are looking for a passive hydrophone system
- We wish to listen after underwater and surface noise, not any kind of marine life
- The solution should be able to operate autonomously for about a year, with only one or two maintenance checks a year
- The solution should provide real time data from the system
- We need to add a control-system to sanity-check the acquired sound data - in this case a time-lapse camera mounted at the shores of the lake
- And it shouldn't be too expensive

1.2 Contribution

The use of sensor networks in aquatic environments has been quite limited, partially due to the harsh underwater environments and associated high system costs. Hydrophones, as a sensor, have only recently been integrated into underwater sensor network installations and testbeds, despite the fact that they are well-known and powerful tools for leveraging the task of localized sound monitoring underwater.

We present the design and implementation of a small-scale prototype for a hydrophone equipped sensor network for long-term deployment under the extreme weather conditions in the arctic.

1.3 Outline

In the first part of this project we review a small but relevant part of the terminology regarding hydrophones (Chapter 2) and describe and analyze the design space and corresponding design choices (Chapter 3). In the second part we discuss the implemented prototype (Chapter 4) and conducted tests (Chapter 5) and in the third and final part we will evaluate and conclude on the findings (Chapter 6).

Chapter 2

Hydrophones

A *transducer* is an electronic device that converts energy from one form to another, whereas a SONAR (SOund NAvigation and Ranging) is a technique which uses sound under water to navigate or detect other vessels. The sonar works after the same echo-principles as a RADAR (RAdio Detection And Ranging). Sonars are classified into two main categories depending on their mode of functioning:

Active sonars - transmitting a signal and receiving echoes from a target. The measured time delay is used to estimate the distance between the sonar and its target and receiving the signal on a suitable antenna completes the measurement with a determination of the angle of arrival of the signal. Active sonars are also called projectors.

Passive sonars - are designed to intercept noises (and possible active sonar signals) radiated by a target vessel. Their main interest lies in their total stealth. Passive sonars are also called hydrophones.

The first underwater echo detection systems were developed by British, American and French scientists for the purpose of underwater navigation by submarines in World war I and in particular after the Titanic sank in 1912. Their two primary functions was to locate submarines and icebergs, but these earliest systems, only worked at relatively high frequencies, and achieved detection ranges of only several thousand yards under favorable conditions. Between the two world wars the sonar technology improved considerably. It benefitted from the emergence of first-generation electronics and from progress in the newborn radio industry. In the aftermath of World War II, the Cold War between the Western and the Eastern blocks, ensured continued focus on the efforts in the scientific and technological research on underwater acoustics[2].

In parallel with military developments oceanography and industry were able to profit from the development of underwater acoustics. For instance the invention of the sonic depth finder (SDF) in the early 1920s, facilitated a detailed depth and ocean-bottom

surveys with a speed and accuracy never before available using the traditional lead-line techniques to measure water depth. Several systems became wide spread and are today used as both scientific instrumentation and indispensable navigation tools.

2.1 Terminology

Acoustic waves originate from the propagation of a mechanical perturbation. Local compressions and dilations are passed from one point to the surrounding points because of the mediums (the water) elastic properties. The propagation rate of the perturbation of the medium is called the *velocity*. But the propagation velocity of an acoustic wave is also imposed by the characteristics of the propagation medium - it depends on the *density* p and the *elasticity modulus* E[1].

$$c = \sqrt{\frac{E}{p}}$$

In sea water, the velocity of the acoustic wave is close to c = 1.500 m/s, with small variations due to pressure, salinity and temperature. The density of sea water is approximately p = 1.030 kg m^{-3}. Fresh water has the density of p = 1.000 m^{-3}, so sea water is about 3% more dense than fresh water. This compared to air where the respective values of sound velocity and density are approximately 340 m/s and 1.3 kg m^{-3}. Water has the anomalous property of becoming less dense, not more, when it is cooled down to its solid form, ice. It expands to occupy a 9% greater volume in this solid state, which accounts for the fact of ice floating on liquid water.

Acoustic signals are characterized by the number of vibrations per second - the *frequency* f expressed in Hertz. The frequencies used in underwater acoustics range roughly from 10 Hz to 1 MHz, depending on the application.

For a sound velocity of 1.500 m/s, the underwater acoustic wavelengths will be 150 m at 10 Hz, 1.5 m at 1kHz and 0.0015 m at 1 MHz.

2.1.1 Propagation losses

The propagation of a sound wave is associated with an *acoustic energy*, expressed as either the *acoustic intensity* I or the *acoustic power* P. Intensity and power can vary enormously. A high-power sonar transmitter may deliver acoustic power of several tens of kilowatt, whereas a nuclear submarine in silent mode might radiate only a few milliwatts. When acoustic waves propagate, the most visible process is their *loss of intensity* because of geometric spreading (a divergence effect) and absorption of acoustic energy by the propagation medium itself. This *propagation loss* or transmission loss is a key parameter for acoustic systems. Sea water is a dissipative propagation medium - it absorbs part of the energy of the transmitted wave. We also call the gradual loss in

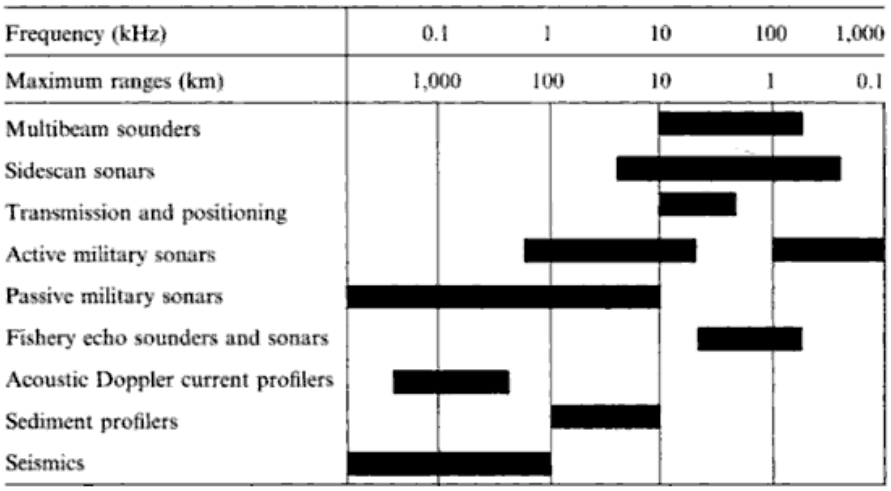

Figure 2.1: **Frequency ranges of the main underwater acoustic systems [1]**

intensity of any kind of flux through a medium for *attenuation*.

Because the propagation medium is limited by the sea surface and the seabed, the signals transmitted undergo *reflections* at the interfaces. Any given signal can therefore propagate from source to receiver along *several distinct paths* (multiple paths). The main signal arrives along with a series of echos, of amplitudes decreasing with the number of reflections undergone. It is called *backscattering*, when the reflection of an acoustic wave collide with an obstacle in the water or at the limits of the medium and reflects the acoustic wave and send an echo of the signal back to the direction they came from. It is a diffuse reflection, as opposed to a specular reflection like a in a mirror. The time structure of the signal is somewhat affected and the performance of a system can be highly degraded by these parasite signals. Depending on the application the echoes can be either desirable or undesirable - if they are completely jamming the useful signal.

In general there are four factors that are peculiar to the arctic environment which complicate the modeling of acoustic propagation:

1. the ice keels present a rapidly varying surface
2. the reflection, transmission and scattering properties at the water-ice interface are not well known
3. the measurement of under-ice contours is difficult and
4. the diffraction of sound around ice-obstacles may be important

Due to scattering at the rough boundaries of the ice, only low frequencies (typically less than 40 Hz) can propagate to long distances in the Arctic channel.

2.1.2 Causes of noise

Noise is an important component of underwater acoustics. The cause of noise can be grouped into four categories:

- Ambient noise - typically originates from factors outside the system and stems from natural or man-made causes.
- Self-noise - typically from the systems own electronics
- Reverberation - typically caused by parasite echoes, but only affects active sonar systems
- Acoustic interference - typically generated by other acoustic systems nearby.

The two first categories are the ones most likely to cause interference in our system.

By definition, ambient noise is the noise received by the sonar in the absence of any signal and self-noise from the system. Ambient noise has several very distinct physical origins, each corresponding to particular frequency ranges:

- Seismic and volcanic activity (very low level frequencies)
- Shipping and industrial activity (from 10Hz - 1kHz)
- Surface agitation depends on sea state and wind speed. (from a few hertz to a few tens of kHz)

We don't anticipate any noteworthy seismic and volcanic activity close to our system and shipping will not pose a problem, as the hydrophone is to be deployed in a freshwater lake. Surface agitation on the other hand - will prove very interesting to measure.

Air bubbles are created by sea surface movements for instance by heavy rain and cause ambient noise. They form an inhomogeneous layer close to the surface, whose dual-phase mixing modifies locally and strongly the acoustic characteristics of the propagation medium (velocity and attenuation). This process decreases in importance as depth increases, because the hydrostatic pressure increases. Below 10 - 20 meters the effect of bubbles can be neglected.

In the mid-frequency band (200 Hz - 50 kHz), the dominant noise source is wind acting on the sea surface. It has been shown, that there is a strong correlation between ambient noise and wind force or sea state. Ambient noise increases about 5dB as the wind strength doubles. Peak wind noise occurs around 500 Hz, and then decreases about -6dB per octave.

Frozen lakes are known to give off most noise during major fluctuations in temperature: the ice expands or contracts, and the resulting tension in the ice causes cracks to appear. Due to the changes in temperature, the hours of morning and evening are usually the best times to hear these sounds. Thin ice is especially interesting for acoustic phenomena; it is more elastic and sounds are propagated better across the surface. Snowfall, on the other hand, has a muffling effect and the sound can only travel to a limited extent. The ice sheet acts as a huge membrane across which the cracking and popping sounds spread.

2.1.3 The Passive Sonar Equation

The sonar equations are founded on the basic equality between the desired (signal) and undesired (background) portions of the received signal. For a sonar to successfully detect an acoustic signal we require that it is above a detectable threshold (DT) :

$$SignalLevel > BackgroundLevel$$

Signal to noise ratio is an important concept because it represents the degree to which an amplifier can be successfully employed to improve the situation. If the signal to noise ratio (S/N or SNR) is too low, the noise is nearly equal to the signal. In this case, amplification will also increase the noise and provide no substantial improvement. For high signal to noise ratios, amplification will improve the magnitude of the signal relative to the noise. We can express this correlation with the passive sonar equation:

$$SNR = SL - TL - NL + DI$$

where SL is the source level, TL is the transmission loss, NL is the noise level, and DI is the directivity index. The directivity index DI for our network is zero because we assume omnidirectional hydrophones. All the quantities in the equation are in dB re μPa, where the reference value of 1 μPa amounts to $0.67 \times 10^{-22} Watts/cm^2$.

$$SL = 10log\frac{I_S}{I_0}$$
I_S = Signal Intensity
I_0 = Reference Intensity - 1 μPa

The origin of these two terms is the intensity of the signal that is transmitted to the water from the target. This is called the Source Level (SL).

$$TL = 10log\frac{I_S}{I_R}$$ (For a plane wave)
I_R = Received signal intensity

As the signal travels through the water, some of the signal is lost through various propagation losses. The totality of this loss is quantified as the Transmission Loss (TL). As a general rule, Transmission Loss is dependent on the distance between the source and the receiver.

$$NL = 10log\frac{I_n}{I_0}$$
I_n = Noise intensity

The Noise Level (NL) is the sum of the total effect of background and self-noise hindering our ability to detect the target signal. An average value for the ambient noise level NL of 70 dB is a representative of the shallow water case[4].

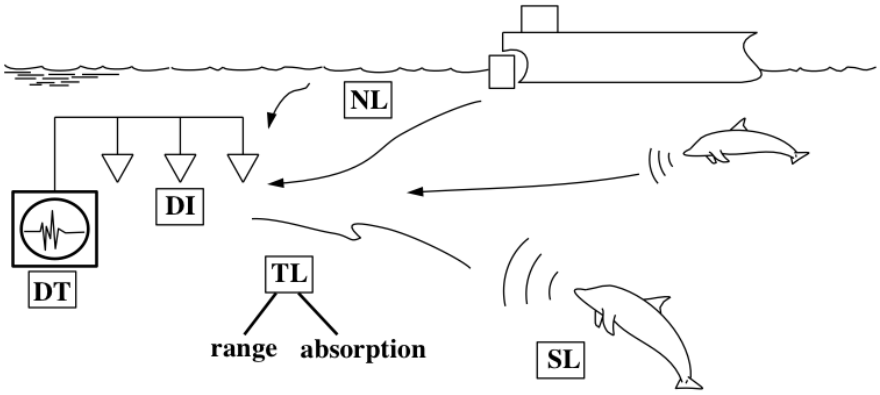

Figure 2.2: **The Passive Sonar Equation**

Chapter 3

Design

In the following we will analyze how to design the hydrophone equipped sensor network. It's important to realize that the hydrophone equipped mote will at some point be part of the existing research installation at Zackenberg, and some consideration to the current setup and infrastructure should be taken. For instance, there is already a buoy in the lake with an Arc rock based IPSerial mote inside[5], which might have space for the hydrophone equipped mote too. If not, another buoy should be bought for the deployment of the hydrophone into the lake. Also there is a GW installation on the shore of the lake, with a working wireless connection to the research station some 4 km away. A side from that, the proposed solution will be autonomous from the existing one, to allow maximum independence in case of system failures.

3.1 Sensing

We wish to design and build a sensor network system, centered around the input from two sensors: a hydrophone deployed in the lake and a time-lapse camera mounted on the shore of the lake. The sensor node controlling the hydrophone will wake up at timed intervals and make sound recordings which will be sent to the GW. In order to be able to control and match the sound recordings against some ground truth, we wish to take at least one time-lapse picture a day on which the current weather condition around the lake can be seen. The time-lapse camera provides our eyes in the field during the remote monitoring mission. It is our hope, that we later during the post-processing of the sound recordings can match the recordings to a certain weather situation and a specific noise in the recording.

It might also be a good idea to mount a small weather sensor, so we can pickup on for instance wind speed or very large differences in temperature. So if the wind speed stays above a certain threshold for a longer period which could be a favorable condition for our sound monitoring, we wish to wake up our sensor nodes to perform extra

measurements. We cannot afford energy wise to do this very often, but it will most likely provide us with recordings of extreme situations, which can help set the normal recordings into the right context and give us a larger data set which will provide more detail and precise information. Preferably the data set from the first 6 months should be used to debug and fine tune the system for the next deployment period.

3.1.1 Choosing a hydrophone

For the sake of simplicity we have selected 4 hydrophones for consideration - two in the cheap range: the Aquarian H2A hydrophone[1] and the DolphinEAR[2] and two in the expensive range: a RESON[3] TC4032 and a Brüel and Kjær[4] 8103 Miniature Hydrophone. They are all omni-directional and passive listening devices. All four are from well known companies and very reliable.

	Aquarian	DolphinEAR	RESON	Brüel and Kjær
Description	H2A	DE100 Series	TC4032	8103 Miniature
Frequency	10 Hz - 100KHz	7 Hz - 22 kHz	5Hz to120kHz	0.1Hz to 180 kHz
Power	0.3 mA	Approx 7 mA at 9V	19mA at 12VDC	6mA without load
Sensitivity	-180dB re 1V/μPa	-	-170dB re 1V/μPa	-211 dB re 1V/μPa
Connector	3.5 minijack	3.5 minijack	LEMO	10-32UNF microdot plug
Pre-amplifier	internal imp. buffer amp	external PA amplifier	low-noise 10dB	external amp
Cable	not included	8 m	6 m	10 m
Price	159$	319 $	DKK 17.887,00	-

Table 3.1: Comparison of 4 different hydrophones

We will be doing measurements about 3 meters down in the lake, free from the ice cover, which is roughly 2 meters thick during the winter. The lake is about 6 meters deep, so this would put the hydrophone right in the middle between the water surface and the lake bottom. The two expensive hydrophones are built to withstand deep underwater pressure of 500 m depth or more. Since we are doing our measurements in what may be characterized as shallow water, the extra endurance of the expensive hydrophones might not be necesarry. However the hydrophone might still get trapped in the ice during spring when the ice melts and refreezes and extra care needs to be taken to protect the wire connecting the hydrophone to the mote, as the ice can be very sharp. The wire should be packed in an isolating pipe (which shouldn't make too much noise when crushed) to relief some of the pressure from the ice, which will form around it during the winter. A good design choice could be to go for one of the cheaper type of

[1] http://www.afabsound.com/home.php
[2] http://www.dolphinear.com/de-specs.htm
[3] http://www.reson.com/sw3154.asp
[4] http://www.bksv.dk/Products/TransducersConditioning/AcousticTransducers/Hydrophones/

hydrophones or build one ourselves since there is a high risk of loosing it during winter.

Figure 3.1: **The DolphinEAR De100 hydrophone**

Looking at the coating of the four hydrophones all three but one looks very sturdy. The DolphinEAR is not packed in the same hard cover as the rest of the hydrophones - its piezoelectric membrane is much more exposed, which means it might be unfit for an arctic deployment. The missing coating will also make it much more exposed to corrosion during the year long deployment, compared to the other three.

When listening for noise it's a good idea to choose the broadest possible frequency bandwidth, but that costs power. The DolphinEAR is the hydrophone with the smallest frequency span, whereas the Brüel and Kjær hydrophone has the broadest frequency span. They are all however, within the frequency span, which is relevant for noise observations. They all claim to have low-self noise, which is important when listening for ambient noise. We want to be able to hear the signal, it shouldn't drown in electro-static noise from the system itself. You normally apply a high pass filter over the recording to remove the noise, but this might not be possible as we then might also remove the valid noise signal we are listening for.

The power requirement is highly relevant for the lifetime of the application. Increasing the intensity and the pre-amplification of the hydrophone signal requires higher power. The higher power drain combined with the arctic environment with below 0 temperatures for half a year at a time will most likely deplete the battery faster than we anticipated. A device called a battery guard[5] might be worth considering into the setup. These are voltage monitoring devices that vary in complexity and capability and they prevent the excessive discharge of the battery (which would damage the battery) and protects electronic appliances against over- voltage. They can turn off any device operated through it when the battery voltage drops below a critical point. On the other

[5]http://www.elfrasolen.dk/Produkter/Batterivagt/index.htm

hand - the battery might be the cheapest part of the whole design, and we want to keep on sampling for as long as absolutely possible, even if that means depleting the battery completely. It might be a better solution to choose a smaller dynamic frequency range and a small sample rate to reduce the power drain.

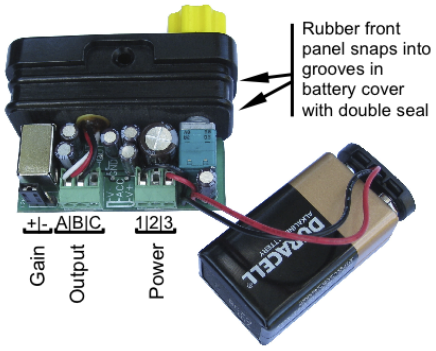

Figure 3.2: **The Aquarian UP1 pre-amplifier inside**

The signal we receive from the hydrophone will most likely need some sort of pre-amplification, otherwise it will be too weak. Usually a professional external amplifier is used to enhance the signal further, but including that in the on site setup is not recommendable. It would require even more space for hardware and even more power. The RESON hydrophone comes with a built-in 10dB pre-amplifier, and with the DolphinEAR a small external amplifier is included, but mostly the hydrophone suppliers lets you buy the pre-amplifiers as an extra accessory. Instead of buying one, we could also build one ourself and integrate the preamplifier into an add-on sensor board placed on the sensor node. We will need an add-on board anyway, since we need to connect the the hydrophone to the sensor node.

Our recommendation would be to go for a cheaper hydrophone fx. the Aquarian H2a[6]. It's sturdy, cheap and has a low power consumption, which makes it ideal for our usage. The price for the Aquarian H2a hydrophone does not include pre-amplification or cables, but it still has a price well below the RESON hydrophone. The low price, also means that an extra spare can be bought, so should the hydrophone be damaged during winter, it can be changed at the first possible maintenance check without loosing the possibility of doing measurements the rest of the year.

3.1.2 Time-lapse camera

Our second sensor for the system is a time-lapse camera, which should be mounted on the shores of the lake. Harbortronics[7] sells such a complete time-lapse package for

[6]Its also the primary choice for many hobby recording artists, which illustrates its ease of use
[7]https://www.harbortronics.com/Products/TimeLapsePackage/

Figure 3.3: **The Aquarian H2A hydrophone with external pre-amp**

remote monitoring. The solution includes:

- Fiberglass Housing, glass window
- High capacity internal Lithium-Ion Polymer battery pack.
- 5 Watt Solar Panel
- Harbortronics Solar Charger
- Harbortronics Battery Converter
- Harbortronics DigiSnap 2100
- Canon Rebel XS (1000D) camera
- A pair of 8 GB memory cards
- All required tools, cables, manuals and accessories

The enclosed camera is a Canon Rebel XS (1000D) which shoots with 10.1 Megapixel, with a maximum resolution of 3888x2592 pixels. There's the choice of two lower resolutions, and all three sizes can be recorded with either Fine or Normal JPEG compression. Its also possible to record RAW files either with or without a Large Fine JPEG. Best quality Large Fine JPEGS typically measure between 3.5 and 4 MB each, while RAW files measure around 10MB each. Shooting in RAW format and saving them on the 8 GB SD card gives us room for about 800 pictures, but if we choose Large Fine JPEGs we have room for more than twice as many pictures, roughly 2000. With the RAW format we can do two pictures a day, with the Large Fine JPEGs we can take five pictures a day for a whole year without filling up the card entirely. But SD cards comes cheap these days, so we would recommend buying a pair of 32 GB cards, leaving plenty of room

Figure 3.4: **The Harbortronics Time-Lapse package**

for pictures. Energy tests in the lab should be performed to see how much power is consumed by powering on the camera, taking a picture and shutting it down again, to measure what is the safe limit for how many pictures can be taken, if the solution is to operate at least 6 months without human interference.

The perhaps most important device apart from the camera itself, is the Digisnap 2100, which controls the camera trigger. The DigiSnap can be configured for either A Simple Time-Lapse (STL) sequence, which consists of an initial delay, followed by a number of pictures taken with a particular interval between each picture or an Advanced Time-Lapse (ATL) sequence, where a set of Time-Lapse sequences can be programmed to start at particular times of the day, but the DigiSnap controller does not have a 'real-time' internal clock, so once powered up it will presume that it's midnight. In terms of connectivity, a flap on the left side of the camera body opens to reveal the TV output, a socket for the optional RS-60E3 remote switch and a USB port. The Digisnap controller connects to the shutter release jack (the RS-60E3 pinout). The interface is very simple, generally just a switch contact. The Digisnap controller is configured by connecting a null-modem cable between the controller and a PC/Mac and using a simple terminal program.

Energywise the package comes equipped with a single high capacity Lithium-Ion Polymer (LiPoly) rechargeable battery pack, having a nominal voltage of 11.1V, and 9AH capacity. The fully charged LiPoly battery pack has enough capacity for about 2 months of operation between charges, depending on the details of the application. The most common battery chemistry for long term, remote applications is lead-acid. Unfortunately,

lead-acid batteries have a number of drawbacks - they are large and heavy and they can vent gases during charge and discharge, making them inadvisable to install within a sealed housing. Most other secondary (rechargeable) battery chemistries have high self-discharge, meaning that they won't work well in a long term application. LiPoly batteries however, have low self-discharge, are very light-weight, and quite compact. The Digisnap controller operates on an internal 5V supply, but is typically also powered by the LiPoly battery-pack though the battery converter. When the DigiSnap is off, there is a load of 8-10 uA on the battery. For the lowest power consumption, the camera should be configured to not turn the LCD back display automatically on, as it is a sure battery drain, but also to set the following options:

- Auto power off : 1 minute
- Manual focus: Shake Reduction Off

The solution also includes a 5W solar panel, which can be exchanged for a larger panel if necessary. At Zackenberg which is located at (74°30'N / 21°00'W) in North-East Greenland 25 km north-west of Daneborg, there is a partial midnight sun in the period from May 2nd - August 12th. Its four months of summer and 8 months of winter darkness. While the 5W solar panel will be more than enough to recharge the battery during the summer, it could be a good design choice to have a larger 20W solar panel[8] for the transition into winter, so it's possible to recharge the batteries even with fewer hours of light. The solar charger, that comes included in the time-lapse package can be reused. Harbortronics recommends that the solar panel rests on top of the housing, where it can also serve as a rain shield to minimize drops on the front window of the housing. With a larger solar panel, that might not be possible, if the solar panel should be placed in the optimal 45 degree angle.

Apart from shielding the wires from wildlife, the user guide gives no other indications as how to shield the box from the arctic environment. A snow storm might possibly cover the window, with snow and ice, leaving the camera 'blind'. It will most likely be worthless to isolate the box itself, as the cold would still penetrate the glass window, but isolating the battery could prove a good investment for the battery-lifetime.

The Harbortronics solution seems very stable. The university of Alaska has tested the system at low temperatures in their facilities and they found that the system worked all the way down to the lowest tested temperature, -60C. However, at –40C and below, some pictures were missing from the sequence. Some of the pictures were dark, others half light / half dark, suggesting that the mechanical items in the camera, the shutter and the mirror assemblies may have been sticking at times, or otherwise slowed. The timing never varied, suggesting that all of the electronics worked at all temperatures even though the normal operating temperature of most digital SLR cameras is specified for 0C to +40C.

[8] http://dk.farnell.com/solar-panels

The Harbortronics system is an ideal solution for the traditional way of doing remote autonomous monitoring, but it does not provide any hooks for real time data retrieval. Direct simple connection to s sensor network system is not possible, which leaves us with several options. Either the Digisnap 2100 can be replaced with a Digisnap 2800 which includes an external input/output wire where we can connect the sensor node, allowing the sensor node to control the Digisnap, which in turn controls the camera, but a simpler solution might be to remove the Digisnap controller altogether and let the sensor node and its internal clock control the time-lapse sequence of the camera through the shutter release jack.

To retrieve the data we must also connect a USB cable to the camera. A large number of SLR cameras support the Picture Transfer Protocol (PTP) for bulk transfer - which is a widely supported protocol developed by the International Imaging Industry Association to allow the transfer of images from digital cameras to computers and other peripheral devices without the need of additional device drivers. The protocol has been standardized as ISO 15740. But no sensor nodes, that we are aware of, support the protocol at this point in time. PTP is supported on Linux and other free software/open source operating systems such as FreeBSD by a number of libraries, such as libgphoto and libptp as well as the application Gphoto2[9].

In order to get PTP or PTP/IP working, we'll need a very small scale computer with an operating system and a USB port to transfer the images from the camera to the research station through the wireless connection. That could be either a Fit-PC2[10] or Linux on a Gumstix[11] (fx. the Overo Air model), both are probably small and low-power enough to fit inside the fiberglas housing.

But at this point the whole time-lapse solution is getting rather complicated with many separate parts and many possibilities for independent failures. It might be worth looking for a simpler solution with fewer parts. One such simpler solution could be the Campbell Scientific CC640 digital camera[12] for use in harsh environments. The CC640 operates at temperatures as low as -40°C, and image acquisition can be triggered by applying a 5 to 12-volt signal. Images are stored on a CompactFlash card or in a datalogger's memory. The images are stored in a JPEG format, but unfortunately only in 640 x 480 (307,200 pixels) resolution, which is nowhere near the good resolution of the canon SLR camera. The camera is powered by 9 to 15 V with a power drain of 250 mA maximum (operating) and 250 uA typical (quiescent). The camera uses the Pakbus protocol[13] to transfer images. The camera works as a PakBus Leaf node and is not capable

[9] http://www.gphoto.org/
[10] http://www.fit-pc.com
[11] http://www.gumstix.com/
[12] http://www.campbellsci.com/cc640-digital-camera-specifications
[13] http://www.campbellsci.com/documents/manuals/pakbusnetguide.pdf

Figure 3.5: **The Campbell Scientific CC640 digital camera**

of performing any routing. The camera could be connected to a sensor node through the cameras RS-232 output, but in order to retrieve the images, the sensor node would have to understand the Pakbus communication protocol to fetch the images.

Which solution to go for depends on whether the captured images should be retrieved in real time or not. If we just want to control when the pictures are taken, but not retrieve the pictures until the first maintenance check, the Harbortronics solution would be perfect. However if the image data needs to be retrieved periodically, we would recommend to look for a different solution.

3.2 Computing

The existing sensor network at Zackenberg uses the Arc Rock IPserial nodes for computing. The benefit of the Arc Rock nodes[14] is that they offer a whole range of ICMP control and management messages as well as support for full UDP and TCP transport-layer protocols as well as over-the-air (OTA) programming. For the easiest integration it would be best to choose a similar node for the new setup.

However the chip driving the IPserial node is not particularly strong, and some pre-processing on the node might be necessary with the hydrophone as it's sampling at a high data-rate, so the the SunSPOT sensor node platform[15], from Sun Labs, Sun Microsystems (now Oracle) might be worth considering. If offers a 180 MHz ARM-based CPU with 512 KB RAM and 4MB flash. It also offers over-the-air programming and by the end of the summer 2010, it will have a working IP6 stack on top of the 6LoWPAN protocol[16]. It also features different mesh networking protocols. The SunSPOT

[14] http://www.archrock.com/technology/faq.php
[15] http://www.sunspotworld.com/
[16] http://blogs.sun.com/roger/entry/summer_research_assistants_2010

Figure 3.6: **The SunSPOT from Sun Microsystems**

processor board features:

- 180 MHz 32 bit ARM920T core - 512K RAM/4M Flash
- 2.4 GHz IEEE 802.15.4 (a CC2420) radio with integrated antenna
- USB interface
- 3.7V rechargeable 720 mAh lithium-ion battery
- 32 uA deep sleep mode

and the general purpose sensor board (the eDemo board) features:

- 2G/6G 3-axis accelerometer
- Temperature sensor and light sensor
- 8 tri-color LEDs
- 2 momentary switches
- 6 analog inputs
- 5 general purpose I/O pins and 4 high current output pins

Also the SunSPOT offers a range of easy to use add-on boards, allowing us to transform the SunSPOT for instance into an efficient datalogger, by using the eFlash add-on board.

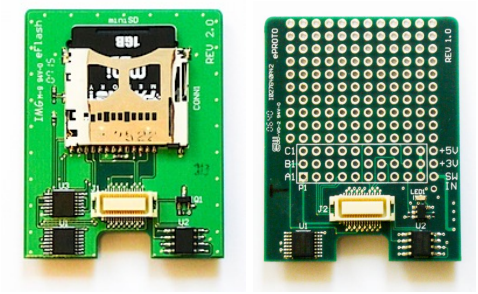

Figure 3.7: **The SunSPOT eFlash and ePrototype add-on boards**

3.2.1 Designing the HydrophoneSPOT

The output from the hydrophone should be connected to one of the sensor nodes Analog to Digital Conversion (ADC) input pins. The SunSPOT comes equipped with the eDemo sensor board which includes the analog device ADT7411 for ADC conversion. The internal oscillator circuit used by the ADC has the capability to output two different clock frequencies. This means that the ADC is capable of running at two different speeds when doing a conversion on a measurement channel. Setting the ADC into single channel mode in SPOT software will change the default sampling rate from 1.4Hz and make the ADC sample at the specified channel every 44.5 microseconds (= 22.5 kHz), although the SPOT will probably not be able to read it faster than every 142 microseconds (= 7.042 kHz) plus whatever loop overhead is needed. So the practical max sample rate using the eDemo board will probably be under 6.9 kHz and, but it would be better to sample faster than that. One option could be to unplug the eDemo board, and stack both the eFlash board and the ePrototype board on top of the SunSPOT. The eFlash board will be used for storage of the acquired data and the ePrototype board for connecting the analog device TI AD7710 which can sample the input signal at a frequency of 39 kHz or greater. This unit was successfully used in the breakout boards of the sensor network doing real time volcano monitoring in Ecuador[9]. Also the ePrototype board can be used for building our own pre-amplifier, with complete control over the gain of the amplification and a tight coupling of the hardware parts.

The benefit of storing the acquired data on the sensor node, allows us to finish sampling before transmitting the data wireless to the GW. The result being, that we can have a high sampling rate without spending unnecessary clock cycles offloading the data while still sampling. When sampling with a high data rate, it will take some time to transfer the data. We propose a classic duty cycle, where the sensor node wake up, does its sampling, forward the data to the GW, do a bit of administrative work like sending information on storage used, battery level left etc, before going back to sleep. The exact length of the sample period will depend on how much battery capacity we can equip the node with while still keeping it inside a buoy.

3.2.2 Designing the CameraSPOT

As for building a time-lapse sensor node based controller for the camera ourselves, several complete guides can be found[17]. It will not require any noteworthy computing efforts, but rather a pretty accurate time keeping which shouldn't drift too much during the year long deployment. Since the arctic circle is on the outskirts of GPS coverage, it would be a better solution to sync its time against the GW with a fixed interval for instance once a month, like its done in the current setup.

3.3 Power estimation

The lifespan of our application depends on how effective our strategy for using the battery will be. One of our primary requirements, is for the system to work autonomously without human interference for at least 6 months preferably longer. As a minimum we need to power the hydrophone, the camera and the two controlling sensor nodes including the pre-amplifier and the eFlash boards for safe storage of data. While the Harbortronics camera solution comes equipped with its own battery (and solar panel) scaled for long-term deployment, the hydrophone needs powering either by itself or through the sensor node which calls for an efficient duty cycle. The firmware of the SunSPOT enables three different modes of operation:

Run	Basic operation with all processors and radio running. Power draw for the eSPOT board is between 70 mA - 120 mA. The eDemo board can consume up to 400 mA if enabled.
Idle	ARM9 clocks and the radio are shut off. Idle power consumption is about 24 mA.
Deep-sleep	All regulators are shut down except for the standby LDO, the power-control Atmega and pSRAM. Deep-sleep power consumption is 32 μA.

Table 3.2: Overview of the SunsPOTs three modes of operation

Deep-sleep cannot be entered if if the radio is on, if external power is supplied or if USB power is on. Deep-sleep and idle modes can be entered through the programming. Waking the processor up from deep-sleep can be done with either an alarm, an external interrupt or by pressing the attention button.

Let's do a rough power estimate. The runtime power draw from the hydrophone equipped sensor node will worst case be around (120 mA + 400 mA) 520 mA (but much can be done to reduce this number). If the goal is a duty cycle of 90/10 (90 % sleep, 10 % awake) spread across a year.

[17] http://www.glacialwanderer.com/hobbyrobotics/?p=13

10 % of 365 days = 36.5 days
36.5 days $\times$ 24 hours = 876 hours / 365 days = 2.4 hours per day
2.4 hours $\times$ 520 mA = 1248 mAH

The capacity of the built-in Lithium-ion battery is 720 milliampere-hours, so we would deplete the battery by using the SunSPOT for 1.38 hours. Now let's try to do the calculation the other way around. Lets assume we can have the SunSPOT turned on for a total of 1 hour over a period of half a year, after which the battery can be changed during maintenance:

60 minutes $\times$ 60 seconds / 180 days = 20 seconds per day

If we only sample once every five days - we could do a 1 minute sample. So our sample period will be 60 seconds.

1 hour $\times$ 520 mA = 520 mAH for the whole period

That leaves 200 mAH on the battery for deep-sleep mode.

180 days $\times$ 24 hours = 4320 hours
4320 $\times$ 32 μA = 138 mAH

which is within the 200 mAH limit. That leaves us with the task of programming either a 99.998/0.002 duty cycle, finding a bigger battery or trying to harvest some renewable energy! But unfortunately it doesn't end there - we must also consider the transmission time of the samples - if we sample at 7kHz for 60 seconds and each datapoint in the sample is one byte, we get:

7000 $\times$ 60 $\times$ 1 = 420 kBytes per minute

According to the CC2420 radio datasheet, the radio has a transmit speed of 250 kbps:

420 kBytes per minute $\times$ 8 bit / 250 kbit per second = 13,44 seconds

which means we have to reduce the sample period from 60 seconds to about **45 seconds**, if we are to preserve energy for both sampling and transmitting the data!

But preferably we would like to sample with 44kHz with the Aquarian H2A hydrophone, which will give us even more data to transfer:

44000 $\times$ 60 $\times$ 1 = 2.640 kBytes per minute
2.640 kBytes per minute $\times$ 8 bit / 250 kbit per second = 84,48 seconds

so for each one minute sample, it will take us 1 minute and 24 seconds to transfer the data. That would require that we reduced the sampling period by more than half. If we still want a 1 minute sample it would have to be **once every fourteen days** or so.

We suggest that we possibly try to find a bigger 3.7V Li-ion battery for the SunSPOTs.

3.3.1 Energy harvesting

In order to prolong the lifetime of the application, we need to consider using the possibility for energy harvesting. Both solar panels and wind turbines have been installed with success on bases in Antarctica proving their sturdiness in a harsh off-grid environment. The most obvious choices would be:

- solar energy
- wave power generation or
- wind power

Unfortunately wave power generation is not currently a widely employed commercial technology, and the lake is covered by ice all winter making it impossible to effectively use this strategy for most of the year. Also setting up a wave generator in the lake in close proximity to our buoy could generate a lot of noise, disturbing our samples. Setting up a wind turbine near the lake is also a possibility, but the force of the arctic storms might take it out. A solar panel will work great during the summer months, but produce little or no power during the dark winter, even though the snow on ground will work as a reflector for the daylight. The solar panel is probably the best value for money solution and in fact there already is a solar panel in the current installation powering the GW during summer, but a hybrid approach combining a wind turbine with a solar panel would probably give a better all-year yield[18]. However the solution needs to be within close proximity to our sensor node inside the buoy, which renders using a wind turbine practically impossible, but a small flexible solar panel might be mounted on the sides of the buoy.

3.4 The hydrophone equipped system

The proposed sensor network system consists of the following parts:

- An Aquarian H2A hydrophone + external pre-amplifier + cables (300 $)
- Harbortronics time-lapse camera solution (2.550 $)
- 2 sensor nodes either SunSPOTs (750 $) or Arch Rock based
- A flexible solar panel for the buoy if possible
- A hard pipe or similar for housing the hydrophone wire
- 1 eFlash and 1 ePrototype add-on boards for the SunSPOT
- 4 SD-cards - two for the camera (32 GB) and two for the SunSPOTs (2 GB)

[18] http://www.wirefreedirect.com/stand_alone_power_system_design.asp

- Hardware for building our own pre-amplifier

We estimate that the solution can be built for less than 5000 $ for the hardware parts.

The sensor network consists of two sensor nodes - one controlling the Aquarian H2A hydrophone and one controlling the shutter control for the time-lapse camera. The hydrophone node should be placed inside a buoy in the middle of the lake with a pipe protecting the hydrophone wire from the ice. The camera node should be placed on the shores of the lake looking out over the lake. A solar panel is mounted on the roof of the camera housing prolonging the lifetime of the battery for the camera. If possible a flexible solar panel should be installed all around the top of the buoy. The hydrophone node is equipped with two stackable add-on cards, an eFlash card for safe storage of the acquired data on a SD-card and an ePrototype board for building our own pre-amplifier. The external pre-amplifier from Aquarian mentioned above is for testing the hydrophone before attaching it to the sensor node. Battery-packs are connected to the two sensor nodes and the camera itself. The solution is estimated to be deployed for a whole year, with at least one maintenance window scheduled after half a year of operation, upon which the SD-cards should be swapped and batteries exchanged for new fully charged ones. The sensor node controlling the camera wake up once a day, to make the camera take a picture. Radio contact is established with the GW once a month to sync time. The sensor node controlling the hydrophone wakes up every 14 days to make a 45 second sample. The data is sent by radio to the GW. Data can be transferred by wifi from the GW to the research camp 4 km away. Depending on the quality and speed of the satellite link from the research camp, data can be forwarded further if possible.

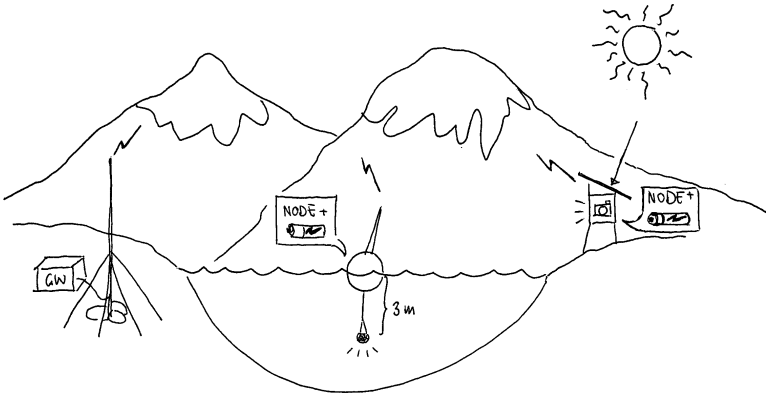

Figure 3.8: **Overview of the hydrophone based sensor network setup**

Chapter 4

Implementation

In the following we will take a look at the actual implementation of the prototype for the HydrophoneSPOT and a corresponding GW application the HydrophoneHOST. We built the prototype in order to obtain some knowledge on the performance of the system, without having access to all the right hardware parts. The result being, that some of the knowledge gained in this process can be directly transferred to the final system, while other parts will have to be redone once the final system is complete.

4.1 Building the prototype

We built the prototype using the Arduino Duemilanove board[1] and a breadboard. The Arduino[2] is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software and using it allowed us to quickly build the hardware while still being able to test it. The finished hardware on the breadboard was then transferred from the Arduino to the SunSPOT, where the actual code for the application was written.

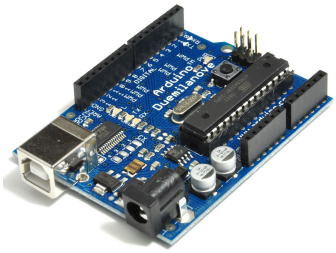

Figure 4.1: **The Arduino duemilanove prototype board**

[1] http://arduino.cc/en/Main/ArduinoBoardDuemilanove
[2] http://www.arduino.cc

4.1.1 Building the hydrophone

A lot of people build their own hydrophone[3] using a simple piezo electric material, a pre-amplifier and a housing, but using a normal electret microphone (in this case a Panasonic WM-61A) works just as well[4]. The Panasonic WM-61A electret microphone support 20 - 20 kHz frequencies. An electret microphone is one of the best value for money omnidirectional microphones you can buy. Electret microphones can be very sensitive, very durable, extremely compact in size and has low power requirements.

Our cheap do-it-yourself (DIY) hydrophone consists of the following parts:

- a cheap pair of headphones
- 2 Panasonic WM-61A electret microphones bought on eBay and
- silicone for making it watertight

We opened up the headphones and desoldered the existing electronics inside the headphones, and then soldered the electret microphones onto the same wires. We then tested the microphones with the normal input jack on a computer using a mic-input. Line-in will not work as electret microphones require a little power to function. We then filled the headphones with silicone and pulled the microphones back into the headphones and wiped the excess silicone off and left it to dry. Afterwards we cut the mini jack off the wire in order to use the wires directly on the breadboard.

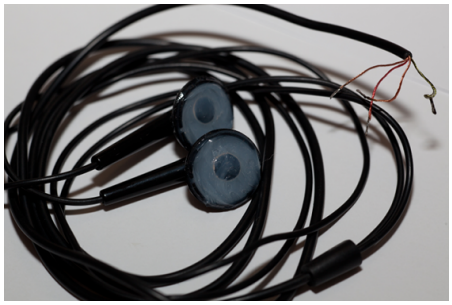

Figure 4.2: **The DIY hydrophone**

4.1.2 Building the pre-amplification

We started out with a very simple transistor-based pre-amplifier from Nerdkits[5], but unfortunately it was very unstable and it only enhanced the signal 6.7 times, which

[3] http://leafcutterjohn.com/?p=915
[4] http://www.freesound.org/forum/viewtopic.php?p=13253
[5] http://www.nerdkits.com/videos/sound_meter/

wasn't enough. So instead we chose a pre-amplifier layout based on the LM386 unit[6]. The LM386 is a power amplifier designed for use in low voltage consumer applications. The gain is internally set to 20 to keep external part count low, but the addition of an external resistor and capacitor between pins 1 and 8 will increase the gain to any value from 20 to 200. The amplified output can be read from pin 5.

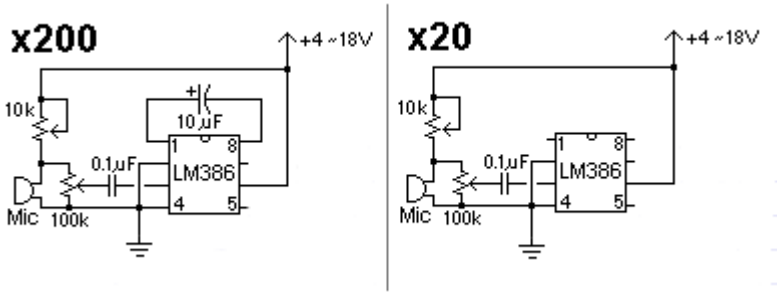

Figure 4.3: **The LM386 based pre-amplifier**

4.1.3 Connecting the hardware

Three wires are connected from the breadboard to the SunSPOT: It receives power from the +5V pinout on the SunSPOT, and it's also connected to the ground pinout. The amplified output from the hydrophone is connected to pinout A0 on the SunSPOT.

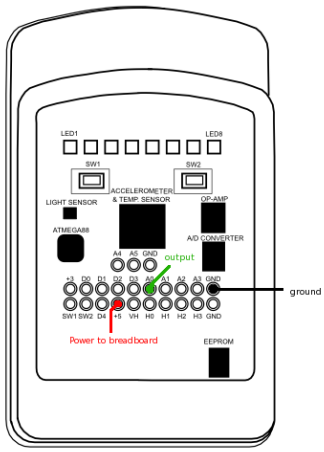

Figure 4.4: **The connection to the SunSPOT**

[6]http://www.josepino.com/circuits/index?mini_amplifier_lm386.jpc

Once the program is deployed to the SunSPOT, sampling can be initiated by pressing the leftmost button. The first LED in the row will light green to show that sampling has begun. The program can be stopped by pressing the rightmost button. When sending data to the host program, the second LED flashes red for each package sent. The use of the LEDs makes it easy to identify the operation of the SunSPOT.

4.2 Prototype limitations

Unfortunately we have not had access to either an eFlash - or an ePrototype add-on board during development. We have been restricted to use the on board 512K RAM and 4MB flash of the SunSPOT. In order not to run out of memory on the SunSPOT it was nescesarry to overwrite the data once it was sent to the host program. We had to change the main sample loop to gather data, and send it as soon as we had enough data to fill a datagram, instead of finalizing all sampling before sending it to the host program. As a consequence our sampling rate is lower than it should be. We start overwriting old data after 7000 samples.

To make matters worse, the SunSPOT have had a problem with enabling the single channel mode. Once enabled the read values don't change at all. The problem might be, that we are trying to read the ADC faster than it is sampling, but as long as this bug persists we are unable to sample faster than 1.7 kHz.

```
public static final byte ADC_REG                = (byte)0x19;
public static final byte SINGLE_CHANNEL         = (byte)0x10;
public static final byte AVERAGING_OFF          = (byte)0x20;

IScalarInput analogIn = EDemoBoard.getInstance().getScalarInputs()[EDemoBoard.A0];
ADT7411 adc = (ADT7411)(EDemoBoard.getInstance().getADC());
// enable single channel mode
adc.write(ADC_REG, (byte)(SINGLE_CHANNEL
                + AVERAGING_OFF + analogIn.getIndex().toInteger()));
```

4.3 Data post-processing

The HydrophoneHOST program simply waits and listens for data. Once received it saves the received hydrophone data to a file on disk. The file can be imported into Audacity[7] as a RAW file. Audacity is a free, easy-to-use and multilingual audio editor and recorder that works on a range of operating systems. Files can be exported to a wealth of formats.

- Encoding: Unsigned 8 bit PCM

[7] http://audacity.sourceforge.net/

- Byte order: No endianess
- Channels: 1 channel (MONO)
- Start Offset: 0 bytes
- Amount to import: 100%
- Sample rate: 1600 Hz

We have not had the time to look into different signal processing schemes for reduction of unwanted noise in the received signal. Further data post-processing will most likely be necessary, before any valid information can be obtained from the data samples.

Chapter 5

Test and evaluation

We have performed initial testing of the hydrophone and the sensor node, but longer tests in a more realistic setting are required. Both regarding the deploy depth, but also regarding the performance in sub-zero temperatures. The initial testing with the Arduino showed that the self made hydrophone was waterproof and responded in water.

Preliminary tests conducted in a kitchen sink showed that the 200 times gain on the pre-amplifier introduced too much noise in the system. With the 20 times gain, we get a clearer but fainter signal, but most importantly it isn't drowned in noise. Test 1 shows it very clearly. The signal to noise ratio is too low. It would have been good, if we had the possibility to slowly increase the gain on the pre-amplifier to find the right level of pre-amplification.

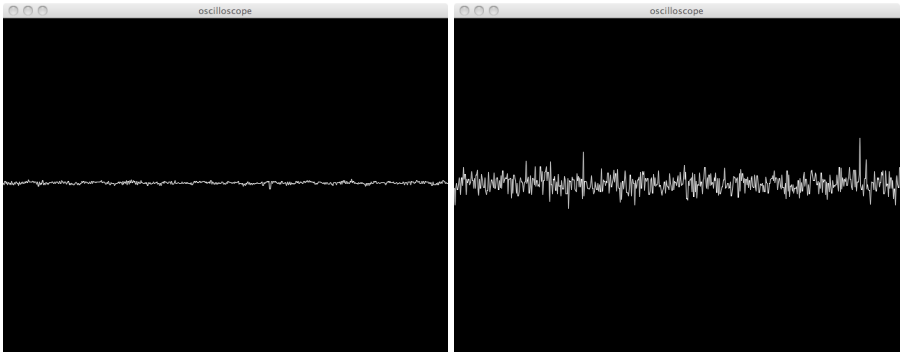

Figure 5.1: **Test 1: Noise level in semi-quiet environment. Left picture is 20x gain. Right picture is with 200x gain**

Kitchen sink test with a running tap right above the hydrophone, which was placed in a bucket underneath:

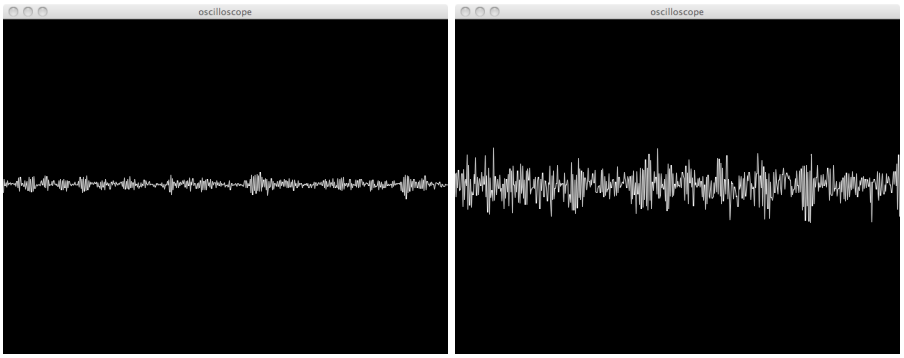

Figure 5.2: **Test 2: Running tap. Left picture is 20x gain. Right picture is with 200x gain**

The third test shows the signal strength when dropping a small rock into the water next to the hydrophone.

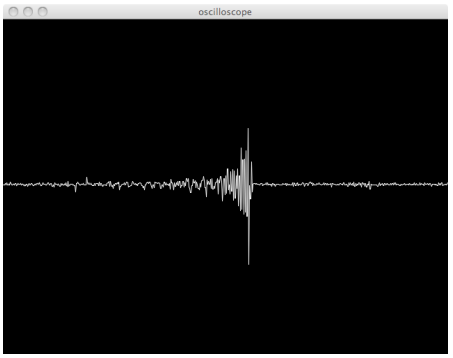

Figure 5.3: **Test 3: Signal strength - picture is with 20x gain.**

We also performed the second and third test, with the running tap and dropping a rock in water with the hydrophone sensor node and ran the data through Audacity, but we were unable to get any recognizable sounds from the sample. It might be because the sample rate is too low, the signal too weak or it might be due to self-noise in the system or all three. The most common cause of self-noise is ground-loops which manifest themselves as a constant 50 Hz tone that doesn't vary with volume. In the screen dump from Audacity (see below) a snippet from a test3 sample can be seen, after removal of line breaks from the file and a normalize of the signal:

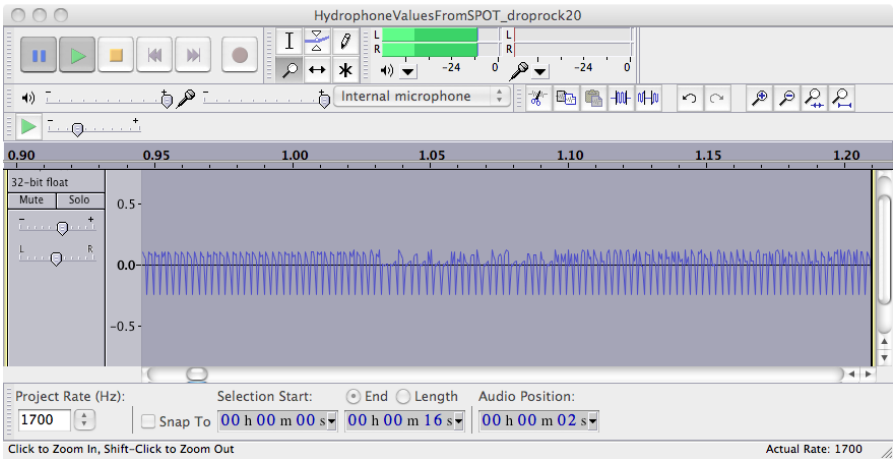

Figure 5.4: **Screendump from Audacity**

At this point in time it would have been really good to be able to substitute the self made hydrophone for a professional one, in order to eliminate some of these problems. We are quite sure the hydrophone works, as seen when using the Arduino, but the Arduino transfers the data through USB, which is significantly faster than the current sample rate of the SunSPOT. With a lower sample rate we lose a lot of data. With a professional hydrophone at hand, we could at least have aligned the samples to find a baseline.

Once the professional hydrophone is available, it could also be very interesting to do some serious power consumption tests for the system. These tests would prove the basis for a recalculation of the duty cycle. If we in any way could reduce the power consumption in run time and combine it with a bigger battery pack, we might have the possibility to wake up more often to sample.

Chapter 6

Conclusion

In this project we have explored the possibility of building and deploying a hydrophone equipped sensor network mote and we have designed and implemented a working prototype of a SunSPOT based mote. Unfortunately we ran out of time while debugging the results of the tests conducted with the self made hydrophone. A minimum requirement is a faster analog-to-digital conversion chip, if the SunSPOTs are to keep up with the sample rate of the hydrophone. Also a better and stronger professional hydrophone is needed in order to establish the actual performance of the system.

We believe it is feasible to build the designed system despite the problems we have experienced with our prototype, but it will require a serious effort to obtain the needed duty cycle with the limited battery capacity to meet the deployment criteria. Also it will require a detailed plan for several longer field-tests before the actual deployment.

Underwater wireless sensor networks does provide a number of advantages and benefits for aquatic applications, but the design and implementation calls for meticulous ground work and demands the utmost of the sensor nodes limited and constrained hardware.

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Appendix A

Source code

A.1 Arduino code

```
// The Arduino code.

#define ANALOG_IN 0

void setup() {
  Serial.begin(9600);
}

void loop() {
  int val = analogRead(ANALOG_IN);
  Serial.print( 0xff, BYTE);
  Serial.print( (val >> 8) & 0xff, BYTE);
  Serial.print( val & 0xff, BYTE);
}
```

A.2 Processing code

```
/*
 * Oscilloscope
 * Gives a visual rendering of analog pin 0 in realtime.
 *
 * This project is part of Accrochages
 * See http://accrochages.drone.ws
 *
 * (c) 2008 Sofian Audry (info@sofianaudry.com)
 *
 * Modified by Sidsel Jensen to save data to file
 */
import processing.serial.*;
PrintWriter output;

Serial port;  // Create object from Serial class
int val;      // Data received from the serial port
int[] values;

void setup()
{
  size(640, 480);
  // Open the port that the board is connected to and use the same speed (9600 bps)
  port = new Serial(this, Serial.list()[1], 9600);
  values = new int[width];
  smooth();

  output = createWriter("output_microphone.txt");
}

int getY(int val) {
  return (int)(val / 1023.0f * height) - 1;
}

void draw()
{
  while (port.available() >= 3) {
    if (port.read() == 0xff) {
      val = (port.read() << 8) | (port.read());
      output.println(val + "\n");
    }
  }
  for (int i=0; i<width-1; i++)
    values[i] = values[i+1];
  values[width-1] = val;
  background(0);
  stroke(255);
  for (int x=1; x<width; x++) {
    line(width-x,   height-1-getY(values[x-1]),
         width-1-x, height-1-getY(values[x]));
  }
}
```

```
void keyPressed()
{
      if (key=='s') {
                output.flush(); // Write the remaining data
                output.close(); // Finish the file
                exit(); // Stop the program
      }
}
```

A.3 HydrophoneSPOT code

```
/*
 * StartApplication.java
 *
 * Sidsel Jensen <purps@diku.dk>
 * HydrophoneSPOT app
 */

package org.sunspotworld;

import com.sun.spot.peripheral.Spot;
import com.sun.spot.sensorboard.EDemoBoard;
import com.sun.spot.sensorboard.peripheral.ISwitch;
import com.sun.spot.sensorboard.peripheral.ITriColorLED;
import com.sun.spot.peripheral.radio.RadioFactory;
import com.sun.spot.peripheral.radio.IRadioPolicyManager;
import com.sun.spot.io.j2me.radiostream.*;
import com.sun.spot.io.j2me.radiogram.*;
import com.sun.spot.peripheral.IBattery;
import com.sun.spot.sensorboard.hardware.ADT7411;
import com.sun.spot.sensorboard.io.IScalarInput;
import com.sun.spot.sensorboard.peripheral.LEDColor;
import com.sun.spot.util.*;

import java.io.*;
import javax.microedition.io.*;
import javax.microedition.midlet.MIDlet;
import javax.microedition.midlet.MIDletStateChangeException;

import javax.microedition.rms.InvalidRecordIDException;
import javax.microedition.rms.RecordStore;
import javax.microedition.rms.RecordStoreException;
import javax.microedition.rms.RecordStoreFullException;
import javax.microedition.rms.RecordStoreNotFoundException;
import javax.microedition.rms.RecordStoreNotOpenException;


/**
 * The startApp method of this class is called by the VM to start the
 * application.
 *
 * The manifest specifies this class as MIDlet-1, which means it will
 * be selected for execution.
 */

public class StartApplication extends MIDlet {

    public static final byte ADC_REG        = (byte)0x19;
    public static final byte SINGLE_CHANNEL = (byte)0x10;
    public static final byte AVERAGING_OFF  = (byte)0x20;
    public static final int  SAMPLE_PERIOD  = 30;   // how many seconds
    public static final int  SAMPLE_RATE    = 7000; // at 7k rate
```

```
public static final int NO_SAMPLES      = SAMPLE_PERIOD*SAMPLE_RATE;

private String message = "empty";
private String BSAddr = "0014.4F01.0000.10C2";
//private DataInputStream in = null;
//private DataOutputStream out = null;
private DatagramConnection dgBS = null;
private boolean talkedtoBS = false;
RecordStore rms;
int recordStoreIndex = 0;

// to measure battery level
IBattery Battery = Spot.getInstance().getPowerController().getBattery();
// to use the Leds
private ITriColorLED [] leds = EDemoBoard.getInstance().getLEDs();

ISwitch sw1 = EDemoBoard.getInstance().getSwitches()[EDemoBoard.SW1];
ISwitch sw2 = EDemoBoard.getInstance().getSwitches()[EDemoBoard.SW2];

IScalarInput analogIn = EDemoBoard.getInstance().getScalarInputs()[EDemoBoard.A0]; // can use

// store about one second of data
private int values[] = new int[7000];

public void connect2GW () {
    try {
        while (talkedtoBS == false) {
            System.out.println("No contact to GW - establish connection");
            if (dgBS == null) dgBS =
            (DatagramConnection) Connector.open("radiogram://"+ BSAddr + ":37");
            Datagram dg = dgBS.newDatagram(dgBS.getMaximumLength());

            sendData("SPOT signing in");
            System.out.println ("Sent: SPOT signing in to basestation");


            Utils.sleep(5000);
            dgBS.receive(dg); // hang here wait for ACK from BS

            message = dg.readUTF();
            System.out.println("Received: " + message);

            while (!message.equalsIgnoreCase("ACK")) {
            //sålænge den kun modtager tomme beskeder så hæng her!
                Utils.sleep(1000);
                dgBS.receive(dg); // hang here wait for ACK from BS

                message = dg.readUTF();
                System.out.println("While loop received: " + message);
            }

            if (message.equalsIgnoreCase("ACK")) {
                System.out.println ("Received: " + message + " from GW");
```

```
                talkedtoBS = true;
            } else {
                System.out.println("Wrong initialisation msg from basestation");
            }
        }
    } catch (IOException e) {
        System.out.println ("No route to 0014.4F01.0000.10C2");
    } finally {
    }
}

synchronized public void sendData(String m){

    try {
        Datagram dgreply = dgBS.newDatagram(dgBS.getMaximumLength());
        dgreply.writeUTF(m);
        dgBS.send(dgreply);
    } catch (IOException ex) {
        ex.printStackTrace();
    }
}

public void startSW1WatchThread(){
    new Thread() {
        public void run(){
            while(true){
                sw1.waitForChange();
                if(sw1.isClosed()){
                    sw1Closed();
                } else {
                    sw1Opened();
                }
            }
        }
    }.start();
}

public void startSW2WatchThread(){
    new Thread() {
        public void run(){
            while(true){
                sw2.waitForChange();
                if(sw2.isClosed()){
                    sw2Closed();
                } else {
                    sw2Opened();
                }
            }
        }
    }.start();
}

public void sw1Opened(){
```

```
        System.out.println("Switch 1 opened.");
    }

    public void sw2Opened(){
        System.out.println("Switch 2 opened.");
    }

    public void sw1Closed() {
        System.out.println("Switch 1 closed.");
        if (!leds[0].isOn()) {
            System.out.println("Start sampling data.");
            leds[0].setColor(LEDColor.GREEN);
            leds[0].setOn();
            connect2GW();
            try {
                sample();
            } catch (RecordStoreNotOpenException ex) {
                ex.printStackTrace();
            } catch (InvalidRecordIDException ex) {
                ex.printStackTrace();
            }
        } else {
            System.out.println("System is already sampling!");
        }

    }

    public void sw2Closed() {
        System.out.println("Switch 2 closed.");
        if (leds[0].isOn()) {
            System.out.println("Stop sampling data.");
            //disconnect from GW
            leds[0].setOff();
        } else {
            System.out.println("System is not currently running!");
        }
    }

    public void sample() throws RecordStoreNotOpenException, InvalidRecordIDException {

        StringBuffer sb = new StringBuffer();
        String msg = "empty";
        int i, value = 1;
        int count = 0;
        byte[] outputData = null;

        // current main loop - read ~1 sec of data and prints it out
        System.out.println("Saving values to RecordStore...\n");
     while (true) {
        for (i = 1; i < 7000; i++) {
            try {
                //add value to RecordStore
                value = analogIn.getValue();
```

```
            Utils.sleep(5000);
            msg = Integer.toString(value);
            try {
                values[i] = rms.addRecord(msg.getBytes(), 0, msg.getBytes().length);
            } catch (RecordStoreException ex) {
                ex.printStackTrace();
            }

            //values[i] = analogIn.getValue();
            count++;
            System.out.println(count + " " + value);

            // pack data in bundles of 15 samples and send
            try {
                outputData = rms.getRecord(i);
            } catch (RecordStoreException ex) {
                ex.printStackTrace();
            }


            if (i == 6999) {
                String data = new String(outputData);
                sb.append(data + " EOF");
            } else {
                String data2 = new String(outputData);
                sb.append(data2 + " ");
            }

            if ((i > 0) && ((i % 15) == 0)) {
            // flash led 2 while sending data
                leds[1].setColor(LEDColor.RED);
                leds[1].setOn();
                msg = sb.toString();
                System.out.println("msg to GW: " + i + " " + msg);
                sendData(msg);
                sb.delete(0, sb.length());
                leds[1].setOff();
            }

        } catch (IOException ex) {
            ex.printStackTrace();
        }
    }

    try {
        // make delimiter between samples
        rms.addRecord("finish".getBytes(), 0, "finish".getBytes().length);
    } catch (RecordStoreException ex) {
        ex.printStackTrace();
    }

    // status on the spot
    System.out.println("Free Memory left on SPOT: " + Runtime.getRuntime().freeMemory()
```

```
        System.out.println("The current battery lvl is: " + Battery.getBatteryLevel() + "%");
        System.out.println("The remaining capacity in mwh is: " + Battery.getAvailableCapacity());
        count = 0;
        i = 0;

        // send remaining data to GW
        msg = sb.toString();
        System.out.println("msg to GW: " + msg);
        sendData(msg);

        // close the recordStore
        //try {
        //    rms.closeRecordStore();
        //} catch (RecordStoreException ex) {
        //    ex.printStackTrace();
        //}
    }
}

protected void startApp() throws MIDletStateChangeException {
    System.out.println("Hello, world");
    new BootloaderListener().start();   // monitor the USB (if connected) and recognize comma

    long ourAddr = RadioFactory.getRadioPolicyManager().getIEEEAddress();
    System.out.println("Our radio address = " + IEEEAddress.toDottedHex(ourAddr));

    System.out.println("The current battery lvl is: " + Battery.getBatteryLevel() + "%");
    System.out.println("The remaining capacity in mwh is: " + Battery.getAvailableCapacity());

    //ADT7411 adc = (ADT7411)(EDemoBoard.getInstance().getADC());
    // enable single channel mode
    //adc.write(ADC_REG, (byte)(SINGLE_CHANNEL + AVERAGING_OFF + analogIn.getIndex().toInteger

    //do the heavy stuff before we start sampling to keep up samplerate
    //create or open RecordStore
    System.out.println("Deleting old RecordStore...(please wait)\n");
    try {
        // if recordstore exists - then delete it so we have room for new samples
        try {
            if (RecordStore.listRecordStores() != null) {
                    RecordStore.deleteRecordStore("SampleData");
                    System.out.println("Done!");
            }
        } catch (RecordStoreException ex) {
            ex.printStackTrace();
        }
        System.out.println("Creating new RecordStore...(please wait)\n");
        rms = RecordStore.openRecordStore("SampleData", true);
        System.out.println("Done!");

    } catch (RecordStoreException ex) {
        ex.printStackTrace();
    }
```

```
        // start program by pressing sw1
        startSW1WatchThread();
        // stop program by pressing sw2
        startSW2WatchThread();
        System.out.println("Press left button to start sampling...");

        // sync time with host
        // after last data sent - send battery and time status
        // go into deep sleep/duty cycle
    }

    protected void pauseApp() {
        // This is not currently called by the Squawk VM
    }

    /**
     * Called if the MIDlet is terminated by the system.
     * I.e. if startApp throws any exception other than MIDletStateChangeException,
     * if the isolate running the MIDlet is killed with Isolate.exit(), or
     * if VM.stopVM() is called.
     *
     * It is not called if MIDlet.notifyDestroyed() was called.
     *
     * @param unconditional If true when this method is called, the MIDlet must
     *    cleanup and release all resources. If false the MIDlet may throw
     *    MIDletStateChangeException  to indicate it does not want to be destroyed
     *    at this time.
     */
    protected void destroyApp(boolean unconditional) throws MIDletStateChangeException {
        for (int i = 0; i < 8; i++) {
            leds[i].setOff();
        }
    }


}
```

A.4 HydrophoneHOST code

```
/*
 * SunSpotHostApplication.java
 *
 * Sidsel Jensen <purps@diku.dk>
 * HydrophoneHOST app
 */

package org.sunspotworld;

import com.sun.spot.peripheral.radio.RadioFactory;
import com.sun.spot.peripheral.radio.IRadioPolicyManager;
import com.sun.spot.io.j2me.radiostream.*;
import com.sun.spot.io.j2me.radiogram.*;
import com.sun.spot.util.IEEEAddress;

import com.sun.spot.util.Utils;
import java.io.*;
import java.text.DateFormat;
import java.util.logging.Level;
import java.util.logging.Logger;
import javax.microedition.io.*;


/**
 * Sample Sun SPOT host application
 */
public class SunSpotHostApplication {

    private static final int    RADIOGRAMPORT   = 37;
    private static final String SPOTADDR        = "0014.4F01.0000.1A32";

    //private DatagramConnection dgBConn = null;
    private String message = "empty";
    private RadiogramConnection conn, conn2 = null;
    private Datagram dgreply = null;
    private Datagram data = null;

    public void connect2spot () {

        try {
            conn = (RadiogramConnection)Connector.open("radiogram://0014.4F01.0000.1A32:37");
            dgreply = conn.newDatagram(conn.getMaximumLength());

            System.out.println("Awaiting connection attempt from SPOT");
            conn.receive(dgreply);

            message = dgreply.readUTF();
            System.out.println("Received: " + message);

            if (message.equalsIgnoreCase("SPOT signing in")) {
                Utils.sleep(5000);
```

```
                data = conn.newDatagram(conn.getMaximumLength());
                data.writeUTF("ACK");
                conn.send(data);
                System.out.println("Sent ACK to client");
                message = "empty";
                //dgreply = null;
            } else {
                System.out.println("Something went wrong!");
            }

        } catch (IOException e) {
            System.out.println ("No connection");
        } finally {
                //conn.close();
        }
    }

    public String lastWord (String s) {
        String lastWord = "";

        int spaceIndex = s.indexOf(' ');
        if (spaceIndex == -1) {
            lastWord = s;
        } else {
            lastWord = s.substring(s.lastIndexOf(' ') + 1);
        }

        //System.out.println("Last word in message is: " + lastWord);
        return lastWord;
    }

    /**
     * Print out our radio address.
     */
    public void run() throws FileNotFoundException, Exception {
        long ourAddr = RadioFactory.getRadioPolicyManager().getIEEEAddress();
        System.out.println("Our radio address = " + IEEEAddress.toDottedHex(ourAddr));

        // initialization of connection variables for radiogram communication
        // wait for SPOT to contact us...
        connect2spot();
        System.out.println("Port " + RADIOGRAMPORT + " is open and listening for a client ...
        System.out.println("Radiogram connection is established with Free-Range SPOT ... ")
        System.out.println("Waiting for incoming data ... \n");

        // Define the date/time format to use
        DateFormat format = DateFormat.getTimeInstance();

        // Variables to write 2 a file
        FileOutputStream    File2OutputData = null;
        PrintStream         MyOutputFile    = null;
        File2OutputData = new FileOutputStream("HydrophoneValuesFromSPOT.csv");
        MyOutputFile    = new PrintStream(File2OutputData);
```

```
        // String to save the data to store on the file
        String Data2Write;
        String data;
        int count = 0;
        StringBuffer incomingdata = new StringBuffer();

        // await incoming data
        while (true) {
            try {
                // Read data received over the radio
                Utils.sleep(50);
                conn.receive(dgreply);
                String addr = dgreply.getAddress();  // read sender's Id

                System.out.println("Data has been received ... ");

                //parse data received
                data = dgreply.readUTF();
                incomingdata.append(data + "\n");
                Data2Write = incomingdata.toString();
                System.out.println("Received from SPOT: " + count + " " + data);
                count++;

                // save hydrophone-data to file

                // have we reached EOF? if so save to file
                if (lastWord(data).equalsIgnoreCase("EOF")) {
                    MyOutputFile.println(Data2Write);
                    System.out.println("Data has been written in file ...  \n");
                    // reset the stringbuffer
                    incomingdata.delete(0, incomingdata.length());
                }

            } catch (Exception e) {
                System.err.println("Caught " + e +  " while reading sensor samples.");
                throw e;
            }
       }

    }

    /**
     * Start up the host application.
     *
     * @param args any command line arguments
     */
    public static void main(String[] args) throws Exception {
        try {
            SunSpotHostApplication app = new SunSpotHostApplication();
            app.run();
        } catch (FileNotFoundException ex) {
            Logger.getLogger(SunSpotHostApplication.class.getName()).log(Level.SEVERE, null, ex);
```

```
            }
        }
}
```